

DEVELOPMENT OF HYDROGEN FUELCELL VEHICLES IN INDIA

-A Review

Submitted in partial fulfillment of the requirements for the completion of

INTERDISCIPLINARY PROJECT

By

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SATHYABAMA



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BONAFIDE CERTIFICATE

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ABSTRACT

India is moving in the right direction to meet its challenging targets for cutting greenhouse gas emissions and expanding the use of clean energy. As a promising way to lessen the carbon footprint of the transportation industry, the development of hydrogen fuel cell vehicles is gaining steam in this context. An overview of the current state of research and development on hydrogen fuel cell vehicles in India, including government objectives, research and development efforts, and industry difficulties and potential, is the goal of this article. The study analyses the role hydrogen fuel cell vehicles can play in the overall decarbonization of the transportation sector, as well as its potential advantages, such as decreased greenhouse gas emissions and enhanced air quality. The document also identifies the major issues facing the sector, such as the high cost of fuel cell technology, the absence of infrastructure for hydrogen refuelling, and the requirement for more in-depth study and development to raise the effectiveness and dependability of fuel cell systems. The article finishes with a discussion of the potential for increased adoption of hydrogen fuel cell vehicles in India, as well as the necessity of ongoing government support and private sector investment to advance the industry.

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LIST OF SYMBOLS AND ABBREVIATIONS

IEA	The International Energy Agency
FCVs	Hydrogen Fuel Cell Vehicles
FAME	The Faster adoption and manufacturing electric vehicles
NHER	National Hydrogen Energy Roadmap
NHEM	Hydrogen Energy Mission
IOC	Indian Oil Corporation
IOCL	Indian Oil Corporation Limited
MMPA	Million Metric Tonnes Per Annum
ATF	Aviation Turbine Fuel
LPG	Liquefied Petroleum Gas
EV	Energy Vehicles
CO ₂	Carbon dioxide
SO ₂	Sulphur dioxide
GE	General Electric
EPA	Environmental Protection Agency
MNRE	Ministry of New and Renewable Energy
IISc	Indian Institute of Science
IIT	Indian Institute of Technology

CHAPTER

1 INTRODUCTION

N

Significant changes in energy policy have occurred all around the world as a result of energy price volatility, scarcity, and environmental deterioration. The threat posed by global warming has grown, according to scientific findings. As a result, the welfare of the global populace has grown increasingly susceptible. Our everyday lives now revolve around transport, which is also vital to the growth of the economy. However, the transportation industry also makes a considerable contribution to greenhouse gas emissions and air pollution. The International Energy Agency (IEA) estimates that the transportation industry is responsible for around 25% of all carbon dioxide emissions worldwide. To minimise carbon emissions and accomplish sustainable development goals in this setting, the development of alternative fuel vehicles, such as hydrogen fuel cell vehicles (FCVs), has become essential. India is currently working to encourage the adoption of FCVs. The National Hydrogen Energy

Mission (NHEM), which aims to encourage the development of hydrogen fuel cell technologies and infrastructure throughout the nation, was unveiled by the Indian government in 2018. The mission's objective is to establish in India a hydrogen ecosystem that would promote the wide adoption of FCVs. The Indian government has established a steering committee as part of the NHEM to direct the advancement of hydrogen technology in the nation. The committee's duties include prioritising topics for research and development and fostering public-private collaborations in the hydrogen industry. Several commercial entities in India have been working on the development of FCVs in addition to various government initiatives. One of the biggest automakers in India, Tata Automobiles has

been developing hydrogen fuel cell technology for its commercial cars. The business has previously created a fuel cell bus, which is presently undergoing testing throughout the nation. The number of developed and advanced countries implementing bold new plans to drastically cut carbon emissions is rising. However, developing nations are now outpacing developed ones in terms of carbon emissions due to their

rapid growth. In fact, Stern predicted that by 2030, the combined emissions from developing nations will make up more than 75% of all emissions worldwide. Because

CHAPTER 2 ENERGY POLICIES IN INDIA

YEAR	ENERGY POLICIES	INFORMATIONS
2015 THE NATIONAL HYDROGEN ENERGY ROADMAP (NHER)	Inclusions of Fuel cell vehicles in FAME Scheme	The Faster adoption and manufacturing of electric vehicles (FAME) scheme was launched in 2015 to provide incentives for the adoption and manufacturing of electric vehicles.
	The promotion of fuel cell buses	The NHER included a pilot project to promote the development of fuel cell technology including in fuel cell vehicles
	Infrastructure development	The NHER emphasized need for the development of hydrogen refuelling infrastructure to support the development of fuel cell vehicles
	Research and development	The NHER included provisions for research and development of fuel cell technology
	International co-operation	The NHER included provisions for international co-operation to support the development of hydrogen fuel cell vehicles

2016	IndianOilCorporation(IOC)	The project aims to showcase any benefits of using hydrogen fuel cells in public transport, such as lower emissions and noise levels.
	Hydrogen energy centre under the ministry of new and renewable energy	The centre aims to facilitate the development of indigenous capabilities in hydrogen productions, storage and utilization.
2017	The national programme on advanced chemistry cell battery storage	This aimed to support the development and production of advanced energy storage technology, hydrogen fuel cells.
	Hydrogen energy and fuel cell programme.	This aimed to promote the development of hydrogen energy technologies in India.
	National hydrogen mission.	The mission aimed to establish the roadmap for the development of hydrogen technologies and create supportive policies.

2019	The faster adoption and manufacturing of electric vehicles (FAME)	In 2019, this scheme is aimed to promote the manufacturing of these vehicles in India and create a supportive ecosystem for their adoptions.
	National Council for Hydrogen and Fuel Cells	This scheme is aimed to promote the manufacturing of these vehicles in India and create a supportive ecosystem for their adoptions. The government had allocated INR 1000 Crores for promotion of electric vehicles.
2020	The faster adoption and manufacturing of electric vehicles (FAME II)	This scheme is aimed to promote the manufacturing of these vehicles in India and create a supportive ecosystem for their adoptions. The government had allocated INR 1000 Crores for promotion of electric vehicles.
	Indian Oil Corporation (IOC)	In 2020, the IOC set up a hydrogen dispensation station in Delhi.
2021	National Hydrogen Mission for faster adoption and manufacturing of electric vehicles (FAME)	In 2021, this policy on hydrogen fuel cell vehicles was focused on promoting the adoption of clean and sustainable technologies in the transport sector, including hydrogen fuel cell vehicles.

2.1 NATIONAL HYDROGEN ENERGY ROADMAP (NHER):

A strategic plan outlining the government's vision and objectives for the advancement of hydrogen energy in India is known as the National Hydrogen Energy Road Map (NHER). Since its first release in 2006, the NHER has been routinely modified to take into account shifting energy demands, scientific discoveries, and international developments in the hydrogen industry.

2.2 OBJECTIVES:

By encouraging the production, storage, and use of hydrogen as a clean energy source, the NHER seeks to establish a sustainable hydrogen economy in India. The NHER's goals are as follows:

2.3 PROMOTING RESEARCH AND DEVELOPMENT IN HYDROGEN TECHNOLOGIES:

The NHER seeks to develop an environment that is favourable for research and development (R&D) in hydrogen technologies, such as fuel cells, electrolyzers, and hydrogen storage systems. This will entail providing money for research initiatives, setting up testbeds, and forming alliances between government, business, and academia.

2.4 ENCOURAGING DOMESTIC PRODUCTION OF HYDROGEN:

The NHER aims to support domestic hydrogen generation using fuels like natural gas, coal gasification, and renewable energy sources (solar, wind, and biomass). India's reliance on imported fossil fuels would decline as a result, and energy security will increase.

2.5 DEVELOPING A HYDROGEN INFRASTRUCTURE:

A strong hydrogen infrastructure, comprising facilities for hydrogen generation, storage, transportation, and dispensing, is what the NHER intends to build. This will

entail adopting standards for hydrogen equipment, establishing a regulatory framework for hydrogen safety, and offering financial incentives for private sector participation.

2.6 PROMOTING HYDROGEN USE IN VARIOUS SECTORS:

The NHER intends to promote the use of hydrogen in a number of industries, including transportation, energy production, manufacturing, and heating. This will entail raising awareness among interested parties, offering rewards for early adopters, and setting up trial projects to show that hydrogen technologies are feasible.

National Hydrogen Energy Roadmap: Vision – 2020

NHERM (2006) Report, Ministry of New and Renewable Energy²

Green Initiative for Future Transport (GIFT)	Green Initiative for Power Generation (GIP)
- Hydrogen cost at delivery point at Rs. 60-70 per kg, hydrogen bulk storage methods and transport via pipeline to be in place - Hydrogen storage capacity to be 9 weight % Support infrastructure- large number of dispensing stations - Development of safety regulations, legislations, codes and 1000 MW hydrogen based power generating capacity setup 1,000,000 hydrogen-fuelled vehicles on road- 50MW small IC engine standalone generators 50,000 two/three wheelers - 50MW standalone fuel cell power packs 50,000 cars/taxis - 900 MW aggregate capacity centralized plants	- Hydrogen bulk storage methods and pipeline to be in place - Support infrastructure- large number of dispensing stations 1000 MW hydrogen based power generating capacity setup standards 50MW small IC engine standalone generators 50 MW standalone fuel cell power packs 900 MW aggregate capacity centralized plants

CHAPTER

3 KEY FEATURES

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3.1 TECHNOLOGY ROADMAP:

The NHER offers an exploration and implementation schedule for hydrogen technology in India. The plan outlines a time frame for completing several milestones, including the introduction of hydrogen refueling stations, the commercialization of fuel cell vehicles, and the creation of a hydrogen economy.

3.2 POLICY FRAMEWORK:

The NHER lays out a framework for policy aimed at advancing hydrogen energy in India. The framework comprises policies to encourage the production, storage, and use of hydrogen, such as tax incentives, subsidies, and regulations. A regulatory framework for hydrogen safety as well as specifications for hydrogen equipment are also included in the policy framework.

3.3 FUNDING MECHANISM:

The NHER offers a means of funding research and development into hydrogen technology as well as the installation of hydrogen infrastructure. Grants, loans, and equity investments from the public and private sectors are all a part of the funding process.

3.4 PARTNERSHIPS:

The NHER aims to create collaborations between government, business, and academia to further the creation and application of hydrogen technologies. To speed up the commercialization of hydrogen technology, these partnerships will involve sharing information, skills, and resources.

CHAPTER 4

PROCESS

4.1 DEMONSTRATION PROCESS:

For the purpose of demonstrating the viability and potential of hydrogen technology, India has started a number of demonstration projects. These initiatives involve the utilisation of hydrogen refuelling stations, fuel cell buses, and forklifts.

4.2 R&D INITIATIVES:

India has launched a number of research and development projects to create hydrogen technology. The National Hydrogen Energy Board, the Hydrogen Energy Centre, and the Fuel Cell and Battery Centre are a few of these programmes.

4.3 POLICY MEASURES:

India has implemented a number of legislative initiatives to support hydrogen energy. Tax incentives for the production are among these strategies.

4.4 THE FASTER ADOPTION AND MANUFACTURING OF ELECTRIC VEHICLES (FAME):

The Indian government announced the Faster Adoption and Manufacturing of Electric Vehicles (FAME) scheme in 2015 to encourage the usage of electric vehicles (EVs) and lessen the nation's reliance on fossil fuels. By offering incentives and support for their development, deployment, and infrastructure for charging, the programme seeks to hasten the adoption of electric vehicles in India. Two steps have been used to implement the FAME programme. The program's initial phase began in April 2015 and lasted until March 2019. April 2019 saw the start of the second phase, which will last through March 2022. The Indian government offers a subsidy to producers of electric vehicles and associated parts as well as financial incentives to consumers who purchase electric vehicles via the FAME initiative. The programme also offers assistance for the construction of an electric vehicle charging infrastructure.

4.5 FINAL INCENTIVES FOR ELECTRIC VEHICLES:

Customers who purchase electric vehicles are given financial incentives through the FAME programme. A variety of electric vehicles, including two-wheelers, three-wheelers, four-wheelers, and buses, are eligible for the subsidies. The incentives offered are based on the electric vehicle's battery capacity and are given in the form of a direct subsidy. The incentive for electric cars with a battery capacity of more than 15 kWh is INR 1.5 lakh (about USD 2,050), whilst the incentive for two-wheelers with a battery capacity of less than 2 kWh is INR 7,000 (around USD 95). Both fleet operators and individual buyers are eligible for the incentives.

4.6 SUBSIDIES FOR MANUFACTURE OF ELECTRIC VEHICLES:

Electric car and related component producers can receive subsidies through the FAME programme. The incentives are offered to encourage the manufacturing of electric cars and lower their price. Batteries, electric motors, and chargers are only a few of the parts that qualify for the incentives. The subsidies amount is based on the component's production cost and is capped at a specific portion of that cost. Lithium-ion battery subsidies, for instance, are capped at 35% of the cost of manufacture, but electric motor subsidies are capped at 20% of the cost of production.

4.7 DEVELOPMENT OF CHARGING INFRASTRUCTURE:

The lack of a charging infrastructure is one of the main obstacles to the use of electric vehicles in India. The FAME programme offers money for the construction of an electric vehicle charging infrastructure. The plan seeks to build charging stations in all significant cities and along important thoroughfares. State governments, public sector organisations, and other groups are given financing for the creation of charging infrastructure. The cash will pay for the equipment, installation, and upkeep costs associated with building charging stations. The FAME programme has been effective in encouraging India to use electric vehicles. More than 6.5 lakh electric vehicles have been sold in India as of March 2021 through the FAME programme.

CHAPTER 5

INDIAN OIL CORPORATION

An Indian public sector oil and gas business with its headquarters in New Delhi is known as Indian Oil Corporation Limited (IOCL). With a net profit of more than Rs 21,000 crore and a turnover of more than Rs 5.5 lakh crore, it is the largest commercial enterprise in India. The Fortune Global 500 list places IOCL as the 83rd largest company in the world.

5.1 HISTORY:

In 1964, the Burmah Oil Company (India) Ltd., Assam Oil Company Ltd., and Indian Oil Company Ltd. merged to form IOCL. At its first refinery in Guwahati, Assam, the company began its operations by refining crude oil. Since then, IOCL has experienced exponential growth, diversifying its business across the full value chain for oil and gas.

5.2 OPERATIONS:

In India, IOCL runs a significant network of refineries, pipelines, marketing, and distribution systems. It is the largest refiner in India, operating 11 distilleries with a combined capacity of 81.2 million metric tonnes per annum (MMTPA). The largest pipeline system in the nation, owned and run by IOCL, spans over 13,000 km and carries natural gas, crude oil, and petroleum products. With over 30,000 fuel outlets in its advertising and distribution network, IOCL provides fuel to over 7,000 bulk users, including the Indian armed services.

5.3 PRODUCTS:

IOCL's product line offers a variety of fuels and lubricants for use in a variety of purposes. It makes kerosene, naphtha, bitumen, aviation turbine fuel (ATF), gasoline, diesel, liquefied petroleum gas (LPG), and furnace oil. In addition, IOCL

produces a variety of petrochemicals and speciality goods, including synthetic lubricants, specialty chemicals, and high-performance fuels.

5.4 INITIATIVES:

In India, IOCL has been in the forefront of the movement to promote clean energy. It has made significant investments in clean energy technologies like biofuels, hydrogen fuel cells, and wind and solar energy. It has also started a number of projects to support electric vehicles (EVs) in India, including building EV charging stations and creating batteries and other EV-related parts. IOCL is also active in a number of programmes for the preservation of natural resources, including waste management, reforestation, and rainwater gathering.

5.5 CORPORATE SOCIAL RESPONSIBILITY:

IOCL has a robust CSR programme that prioritises environmental protection, healthcare, education, and rural development. It runs a number of initiatives to support education for needy kids, including as the "Vidya Jyoti" programme, which awards bursaries to kids from economically disadvantaged groups. Additionally, IOCL runs a number of healthcare facilities, including mobile health vans, and has started a number of programmes to encourage rural development, including the provision of clean drinking water, sanitary facilities, and assistance with subsistence needs.

5.6 RECENT DEVELOPMENT:

IOCL has been actively growing its business both inside and outside of India in recent years. To explore and develop oil and gas reserves in other nations, it has established a number of joint ventures with other corporations. In addition, IOCL has been investing in various petrochemical projects in both India and other countries while looking at potential in the petrochemicals industry.

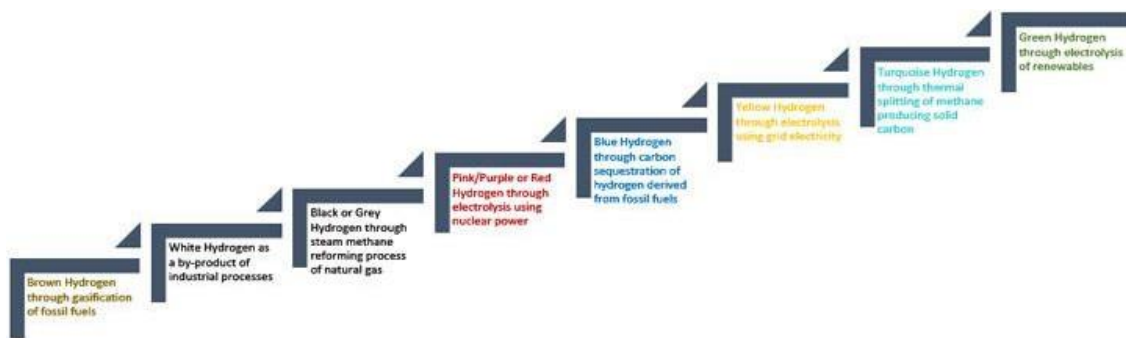


Figure5.1HYDROGENROADMAP

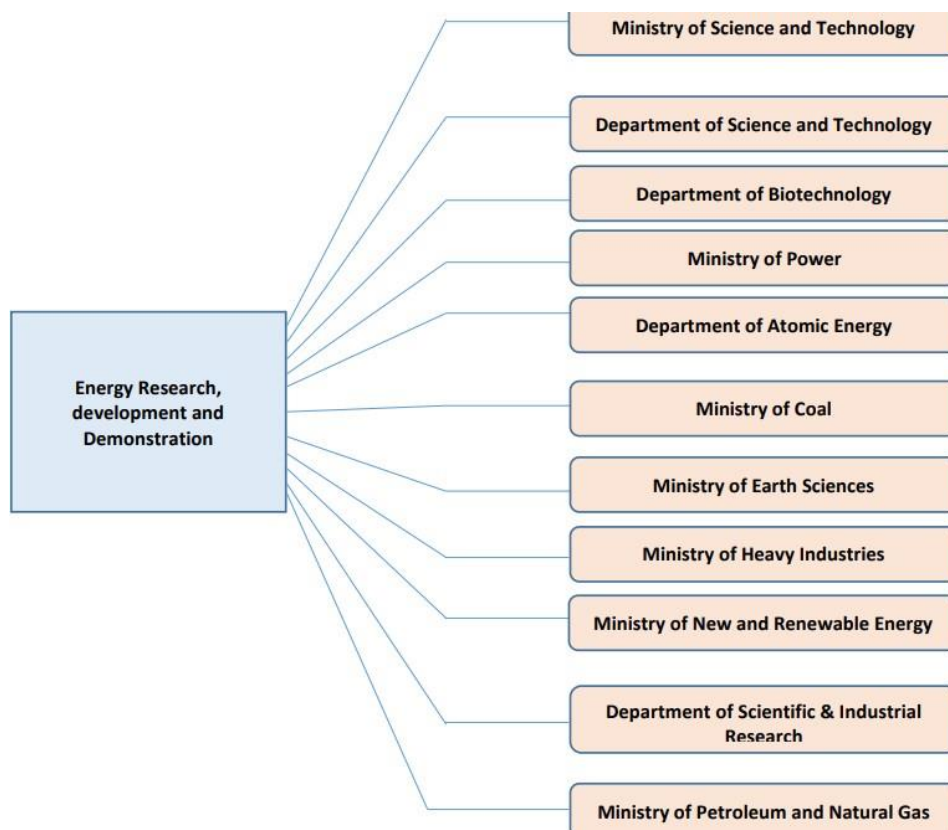


Figure5.2INDIANCOUNTRYSTATUSREPORTONHYDROGENANDFUELCELL

CHAPTER

6HYDROGENFUELCELL

Vehicles with zero emissions that use hydrogen gas as fuel to generate energy to drive an electric motor are known as hydrogen fuel cell vehicles, or FCVs.

FCVs have the potential to completely change the transportation industry and are a promising technology for lowering air pollution and greenhouse gas emissions.

Despite the fact that there are several researches on the use of hydrogen in fuel cell technologies, very few of them focus on underdeveloped nations.

To replace internal combustion engines, automakers have created and tested hydrogen FCVs on the road. To promote the commercialization of zero-emission vehicles, Toyota has opened up hydrogen FCV patents, following Tesla's lead in making electric vehicle patents freely available to other automakers.

These are unusual partnerships between automakers to promote innovation. But in developing nations, it has been difficult to implement alternative vehicle technologies, particularly those that use hydrogen fuel cells. However, the focus on hydrogen FCV has gained traction.

Consumers are becoming more aware of the need to convert from fossil fuels to renewable clean energy sources in order to combat climate change and rising urban air pollution.

A hydrogen fuel cell vehicle (FCV) uses electricity produced by the electrochemical reaction between hydrogen and oxygen, which produces water as a byproduct, as opposed to mechanical energy produced by conventional combustion of fossil fuels. When compared to toxic gases and particles created by the burning of fossil fuels, such as sulphur dioxide (SO₂), nitrogen oxides (NO and NO₂), and carbon dioxide (CO₂), water is a harmless byproduct. rather a secondary energy carrier. However, the majority of the hydrogen produced today still comes from expensive sources.

In the year 2006, the world produced 50 million tonnes of hydrogen, with 48% of that coming from natural gas, 30 percent from oil, 18% from coal, and 4% from renewable sources.

The history, technology, advantages, drawbacks, and possibilities for hydrogen fuel cell vehicles will all be covered in detail in this article. Vehicles powered by hydrogen fuel cells (FCVs) have been around for more than 150 years.

Although the first hydrogen-powered vehicle trials were carried out in the early 1800s, the first useful fuel cell wasn't created until the 1960s. Sir William Grove, a British lawyer and physicist, came up with the idea for the fuel cell in the 1830s.

Grove's creation was based on the concept of mixing hydrogen and oxygen in an electrolyte to produce electricity. NASA and General Electric (GE) started working together to create fuel cells in the 1960s for use in space travel.

The first space shuttles and satellites were propelled by these early fuel cells. General Motors began developing fuel cell technology for use in terrestrial vehicles around this time. Several automakers had created test fuel cell vehicles by the late 1990s.

Toyota unveiled the Prius, a hybrid car that runs on both petrol and electricity, in 1997. The EV1 is an all-electric vehicle that General Motors unveiled the year after. However, the Honda FCX was the first fuel cell car to be approved for use on public roads by the Environmental Protection Agency of the United States (EPA). The Toyota FCHV, a fuel cell vehicle based on the Highlander SUV, was unveiled by Toyota in 2002.

The FCX Clarity, which was the first fuel cell car to be leased to a retail consumer, was presented by Honda the following year. The HydroGen3, a fuel cell vehicle based on the Opel Zafira minivan, was unveiled by General Motors in 2005. The development of fuel cell automobiles spread to other automakers in the years that followed.

The Tucson Fuel Cell, which Hyundai unveiled in 2013, was the first mass-produced fuel cell car that the general public could purchase.

Toyota unveiled the Mirai, a fuel cell car based on the Toyota Lexus, in 2014. Despite these developments, the uptake of hydrogen fuel cell vehicles has lagged behind expectations.

This is largely because fuel cell technology is expensive, there aren't enough hydrogen fuelling stations, and hydrogen has a lower energy density than petrol or diesel. However, in the upcoming years, it is anticipated that the market for fuel cell vehicles would expand.

By 2030, there may be up to 10 million vehicles running on hydrogen, according to an estimate by Bloomberg New Energy Finance. Fuel cell technology has been applied in fields other than the automobile sector, such as building electricity and backup power for data centres.

The utilisation of fuel cells has the potential to significantly lower greenhouse gas emissions and enhance air quality.

6.1 TECHNICAL BEHIND HYDROGEN FCVs:

The electric motor in hydrogen fuel cell vehicles (FCVs) is driven by a fuel cell that produces energy from hydrogen and oxygen. The fuel cell stack, hydrogen storage tanks, and powertrain are only a few of the crucial parts of the FCV technology. The electrochemical reaction occurs inside the fuel cell stack, which is the centre of the FCV.

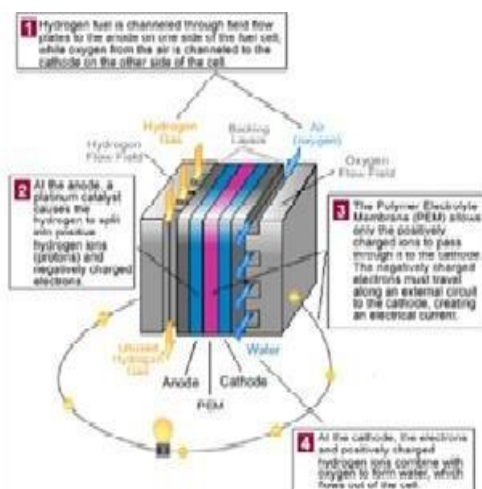


FIG6.1 FUEL CELL

It is made up of several stacked fuel cells, each of which has an anode, a cathode, and an electrolyte membrane. While oxygen from the air is delivered into the cathode side, the anode side receives hydrogen. When the electrolyte membrane is present, the two gases react, creating water and electricity as byproducts.

The electric motor of the vehicle is then driven by the electricity. The compressed hydrogen gas kept in the hydrogen storage tanks serves as the fuel for the fuel cell.

To achieve maximum storage capacity while minimising weight and space requirements, the tanks must be sturdy and lightweight. The majority of FCVs employ high-pressure tanks constructed of metal alloys or carbon fiber-reinforced polymers.

An electric motor drives the wheels of an FCV, which has a powertrain akin to an electric vehicle (EV). However, an FCV employs a fuel cell to generate power as needed rather than relying on a battery to store electricity. As long as there is a supply of hydrogen and oxygen, the fuel cell can continuously produce electricity.

Since water vapour is the only result of the fuel cell operation, one benefit of FCVs is that they have zero emissions. Nevertheless, depending on the source of the hydrogen, the creation of hydrogen itself may produce pollutants.

The majority of hydrogen is now produced using fossil fuels, although creating hydrogen using renewable energy sources like wind and solar power is gaining popularity.

6.2 WORKING DIAGRAM OF HYDROGEN FCVs:

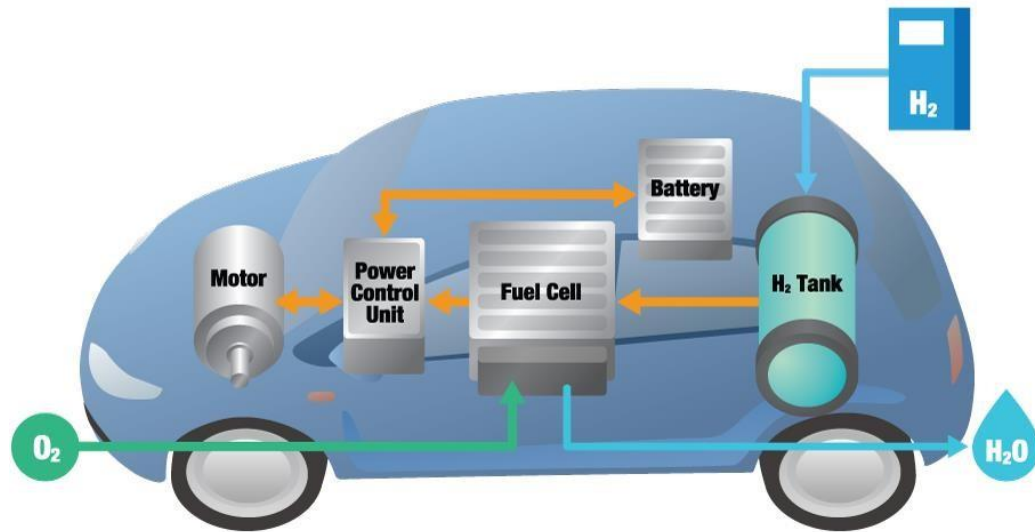


FIGURE 6.1

CHAPTER

7 BENEFITS OF HYDROGEN FCVs

Vehicles driven by hydrogen fuel cells (FCVs) have a variety of advantages over traditional gasoline-fueled vehicles and even electric vehicles (EVs). Here are a few of the main advantages:

- zero Emissions: The fact that FCVs emit nothing at the tailpipe is arguably their most significant benefit. Fuel cell vehicles (FCVs) are an appealing choice for lowering greenhouse gas emissions and improving air quality because the sole result of the fuel cell process is water vapour.

7.1 HIGH EFFICIENCY:

When compared to traditional gasoline-powered vehicles, FCVs are extremely efficient. When compared to gasoline-powered automobiles, their efficiency can reach about 60%, as opposed to about 20% for them. As a result, FCVs are a more feasible option for long-

distancedrivingbecausetheycantravelfartheronasingle

tank of petrol. FCVs operate practically silently, making them an ideal choice for locations that are sensitive to noise, such as residential neighbourhoods.

7.2 FAST REFUELING:

In comparison to the hours needed to recharge an EV, refueling an FCV is equivalent to refueling a gasoline-powered car and just takes a few minutes. Due to this, FCVs are a more sensible choice for long-distance driving.

7.3 LOW MAINTENANCE:

Compared to traditional gasoline-powered vehicles, FCVs require less maintenance because they have fewer moving components. As a result, the vehicle's lifetime maintenance expenses may be reduced.

7.4 FLEXIBLE RANGE:

FCVs can provide flexible range, which means they can be made to accommodate a variety of driving requirements. Some FCVs can be built with a relatively tiny hydrogen tank and fuel cell stack, which makes them perfect for short-distance city travel. Others can be created with a larger hydrogen tank and fuel cell stack, making them better suited for long-distance driving.

7.5 REDUCED EMISSIONS:

One of the most important advantages of hydrogen fuel cell vehicles in India is their lower emissions. Traditional petrol and diesel fueled vehicles are a major contributor to air pollution, which can have a detrimental effect on both the environment and public health. As opposed to conventional automobiles, hydrogen fuel cell vehicles produce no harmful pollutants at all, including carbon dioxide (CO₂), nitrogen oxides (NO_x), or fine particulates (PM). A class of harmful chemicals known as nitrogen oxides can impair breathing while contributing to smog formation. Particulate matter, which is made up of microscopic soot, dust, and other pollutants, has been linked to a number of health issues, including asthma, heart disease, and lung cancer. A greenhouse gas called carbon dioxide plays a role in both global warming and climate change.

Vehicles powered by hydrogen fuel cells can contribute to better air quality and public health in India by reducing emissions. This is especially crucial in metropolitan settings where air pollution is a major concern. The country's carbon footprint can also be decreased with the help of the reduced emissions, which is an important step in reducing the adverse effects of climate change.

7.6 REDUCED CARBON FOOTPRINT:

Reduced greenhouse gas emissions from a person, business, or product are referred to as reductions in carbon footprint. The quantity of carbon dioxide and other greenhouse gases produced into the atmosphere as a result of human activities including transportation, energy use, and food production is known as a person's "carbon footprint." For the purpose of preventing climate change and protecting the environment, reducing carbon footprint is crucial. Among the strategies to lessen carbon footprint are:

7.6.1 ENERGY SUFFICIENT BUILDINGS:

Large amounts of carbon emissions are caused by buildings. We can use less energy to heat, cool, and light buildings by creating them with energy-efficient design and construction.

7.6.2 RENEWABLE RESOURCES:

Carbon footprint can be significantly reduced by utilising renewable energy sources like wind, solar, and hydropower. These energy sources don't release greenhouse gases and are getting more and more accessible and economical.

7.6.3 SUSTAINABLE TRANSPORTATION:

Another significant source of carbon emissions is transportation. We can lessen our carbon footprint by taking the bus, carpooling, biking, or walking as opposed to driving alone.

7.6.4 SUSTAINABLE AGRICULTURE:

The use of fertilisers and other chemicals in agriculture is a major contributor to carbon emissions. We can lessen our carbon footprint by implementing sustainable agriculture practises including crop rotation, utilising organic fertilisers, and cutting back on food waste.

7.6.5 IMPROVED FUEL EFFICIENCY

A vehicle's capacity to use less fuel to cover a specific distance is referred to as improved fuel economy. Reduced fuel consumption minimises greenhouse gas emissions and lowers gasoline costs for car owners. This is the aim of improving fuel economy. For a number of reasons, FCVs have superior fuel efficiency than gasoline-powered cars. First off, hydrogen is a fuel that has a high energy density, or a lot of energy per unit of mass. Because of this, FCVs can drive farther on a single tank of fuel than gasoline-powered cars can. Second, the electrochemical method utilised by FCVs to transform hydrogen's chemical energy into electricity, which powers the motor of the vehicle, is extremely effective. To provide the energy required to run an internal combustion engine, this procedure is more effective than burning Petrol. Third, using a technique known as regenerative braking, FCVs can recover part of the energy that is often wasted while braking. The amount of hydrogen required to power the car is decreased by using this energy to recharge the battery. Overall, drivers should expect to pay less for petrol and have a less environmental effect because of hydrogen fuel cell vehicles' enhanced fuel economy.

7.7 JOB CREATION:

In a number of industries, the advancement and application of hydrogen fuel cell technology have the potential to generate new employment possibilities. The following are some ways that the development of the hydrogen industry could result in employment creation:

7.7.1 MANUFACTURING:

Specialised manufacturing knowledge is necessary for the creation of hydrogen fuel cells, hydrogen storage tanks, and other components of hydrogen fuel

cell cars. Especially in areas with a history of advanced manufacturing competence, this could result in the creation of new jobs in the manufacturing sector.

7.7.2 RESEARCH&DEVELOPMENT:

Ongoing investments in hydrogen fuel cell technology research and development could result in new scientific discoveries, spurring innovation and opening up new employment opportunities for engineers and scientists.

7.7.3 SUPPLYCHAINMANAGEMENT:

A new supply chain will need to be created in order to produce and distribute hydrogen fuel. In the transportation, logistics, and other associated areas, this can lead to the creation of new jobs.

CHAPTER

8 INCREASED ENERGY SECURITY

Hydrogen fuel cell technology has the potential to increase energy security in several ways. Diversification of energy sources: A number of energy sources, including biomass, solar, wind, and natural gas, can be used to make hydrogen. Energy security is increased and dependence on any one fuel source is decreased thanks to this diversification of energy sources.

8.1 DOMESTIC PRODUCTION:

The ability to create hydrogen at home reduces reliance on imported energy sources and boosts energy security. For instance, generating hydrogen from renewable energy sources can lessen the need for imported oil.

8.2 RESILIENCE:

In the event of power outages or other disturbances, hydrogen fuel cells can function independently of the electric grid, giving them a reliable source of energy.

8.3 EMERGENCY RESPONSE:

Emergency response vehicles can be powered by hydrogen fuel cells, offering a dependable supply of energy in catastrophe scenarios.

8.4 POTENTIAL FOR CARBON NEUTRALITY:

Although fossil fuels now account for the majority of hydrogen production, there is growing interest in manufacturing hydrogen using renewable energies like wind and solar power. If this pattern holds, FCVs may eventually achieve true carbon neutrality, making them a more environmentally friendly mode of transportation.

8.5 INNOVATION AND INVESTMENT:

The development of FCVs necessitates a large amount of innovation and investment, which can promote both economic growth and technological improvement. This could lead to the creation of new companies and jobs, as well as improvements in energy storage and related technology.

CHAPTER

9 CHALLENGE

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Hydrogen fuel cell vehicles (FCVs) have the potential to play a significant role in reducing greenhouse gas emissions and improving air quality in India. The broad use of this technology throughout the nation, however, faces significant obstacles. I shall go into great depth on the difficulties in this essay.

9.1 LACK OF INFRASTRUCTURE:

One of the biggest obstacles to the deployment of hydrogen fuel cell vehicles (FCVs) in India is a lack of infrastructure. FCVs need a separate infrastructure for hydrogen generation, storage, and transport than normal petrol or diesel vehicles. In order for FCVs to be a feasible option, a new infrastructure network must be developed because the infrastructure needed for hydrogen fueling is more complicated.

In India, there are now only a very small number of Hydrogen refueling stations, mostly in Delhi and Mumbai. A major obstacle to the general adoption of FCVs is the dearth of refueling stations. It restricts the range and functionality of FCVs, making consumer use less convenient.

A considerable investment is needed to create a nationwide network of hydrogen refueling stations in order to encourage the use of FCVs in India. Government, business, and other stakeholders must work together for the development of this infrastructure. Incentives for the private sector to make investments in the construction of hydrogen infrastructure can be offered by the government.

To encourage the use of hydrogen fuel cell technology throughout the nation, the government has also made plans to establish a National Hydrogen Energy Mission. In order to promote the use of hydrogen fuel cell technology across a number of industries, including transportation, power production, and industrial uses, the mission intends to build an extensive plan. The mission will also concentrate on creating a nationwide network of hydrogen refuelling stations and other hydrogen infrastructure.

9.2 HIGH COST:

The high cost of hydrogen fuel cell vehicles (FCVs) is one of the main obstacles to their widespread use in India. Because of their sophisticated and complicated technology, FCVs are more expensive than typical petrol or diesel vehicles. The most expensive and central part of an FCV's powertrain, the fuel cell stack, is largely to blame for the high cost of these vehicles. The fuel cell stack creates

electricity from hydrogen and oxygen through a challenging chemical process, which drives

the car's electric motor. The fuel cell stack is a crucial part of FCVs, and producing it costs a lot because it needs expensive materials and sophisticated manufacturing techniques. The absence of economies of scale in the fabrication of fuel cell components is another factor raising the price of FCVs. Currently, there is little demand for FCVs, and there aren't many companies making the fuel cell stacks and other essential parts. As a result, the quantities produced are small and production costs are still high. Specialised manufacturing techniques and tools are needed to produce FCVs, which pushes up production costs even more. Nevertheless, the fuel cell stack is not the only component of FCVs that is expensive. The electric motors and high-pressure hydrogen tanks that are part of FCVs are also more expensive than equivalent conventional parts. The restricted availability of FCVs in the Indian market is a result of their high price. FCVs are much more expensive than standard petrol or diesel automobiles, making them inaccessible for the majority of buyers. Furthermore, the usability of FCVs is restricted by a lack of infrastructure for hydrogen fueling, which reduces their appeal to consumers.

It is crucial to lower the cost of FCVs in order to encourage their adoption in India. Increasing FCV production numbers, which can result in economies of scale in the manufacture of fuel cell components, is one strategy to lower the cost of FCVs. By offering subsidies to manufacturers to develop FCVs and fuel cell components, the Indian government may play a vital role in fostering the adoption of FCVs. The government should also promote the use of FCVs in fleet management and public transport, where their high purchase price can be balanced out by the savings they provide on running expenses and the environment. Enhancing the fuel cell stack's efficiency is another option to lower the cost of FCVs. Fuel cell components can be made more effectively and durably while also being less expensive thanks to the development of improved materials and production techniques. Fuel cell technology may advance as a result of research and development in this field, becoming more widely used and more reasonably priced.

9.3 LIMITED AVAILABILITY OF HYDROGEN:

The restricted accessibility of hydrogen fuel cell vehicles (FCVs) is a key obstacle to their implementation in India. Only a few companies are currently making

FCVs, and only a few cities have access to them. The limited supply of FCVs makes it difficult for customers to buy or lease them, which prevents their widespread use in the Indian market.

There are various reasons why FCVs are not widely available. The low production capacity of manufacturers is one of the main causes. It is challenging for manufacturers to swiftly scale up production of FCVs due to the specialised manufacturing procedures and tools needed. Additionally, manufacturers find it less appealing to invest in increasing their production capacity because FCV demand in India is relatively low.

The absence of infrastructure for hydrogen fueling is another barrier limiting the accessibility of FCVs. The availability of hydrogen fuelling stations is currently scarce in India, which restricts the use of FCVs. It is difficult for manufacturers to market FCVs in places without hydrogen fueling stations due to the lack of infrastructure for hydrogen fueling.

The affordability of FCVs is also impacted by their scarcity. Due to their low manufacturing numbers, FCVs are more expensive and therefore out of reach for the majority of consumers. The expensive cost of FCVs prevents them from being widely used in fleet management and public transportation, where their advantages may be more obvious.

Promoting FCV production and availability in India is crucial to addressing the issue of FCVs' restricted availability. By offering manufacturers incentives to increase their manufacturing capacity and by encouraging the construction of hydrogen fuelling infrastructure, the Indian government may play a significant role in fostering the adoption of FCVs.

Giving producers and customers tax incentives is one strategy to encourage the use of FCVs. Manufacturers can lower the cost of FCVs with the use of tax incentives, which will also persuade customers to buy or lease FCVs. Furthermore, by offering monetary incentives for the installation of hydrogen fuelling stations, tax incentives can assist in supporting the development of hydrogen fueling infrastructure.

By funding research and development, the Indian government can also aid in the development of infrastructure for hydrogen fuelling vehicles. Research & development can hasten the development of hydrogen fuelling infrastructure and assist fuel cell technology to become more efficient and affordable.

Promoting the usage of FCVs in fleet management and public transit is another strategy to increase their acceptance. The advantages to the environment and lower running expenses of FCVs can make up for their high purchase price. Promoting the use of FCVs in fleet management and public transportation can aid in developing a market for FCVs, which could result in increased production and accessibility.

9.4 SAFETY CONCERN:

In order to ensure the safe operation of hydrogen fuel cell vehicles (FCVs), important safety issues regarding their deployment in India must be addressed.

The handling and keeping of hydrogen fuel, the possibility of hydrogen leakage, and the flammability and explosiveness of hydrogen gas are all safety considerations. Due to its extreme flammability and explosiveness, hydrogen poses a risk to public safety in the case of a leak or accident. Hydrogen can ignite and explode, causing severe injury or even death, if it comes in contact with an ignition source.

Leakage of hydrogen is another issue with safety. An explosion or fire could result from hydrogen leaks from the fuel cell stack, high-pressure storage tanks, or fuelling infrastructure. In addition to causing an oxygen shortage in the air, hydrogen leaking can also increase the risk of suffocating.

Another key safety problem is how hydrogen fuel is handled and stored. High-pressure tanks are used to store hydrogen fuel, and particular tools and methods are needed to make sure that it is handled and stored safely. In the event of a collision or other catastrophe, the high pressure of hydrogen fuel storage tanks further increases the risk of tank rupture or explosion.

Several steps can be done to assure the safe functioning of FCVs in order to solve these safety concerns. It is crucial to have appropriate safety rules in place for the creation, handling, and application of hydrogen fuel. These rules should apply to the

whole hydrogen fuel lifecycle, including production, transportation, storage, and fueling.

Assuring the safe handling and storage of hydrogen fuel is a crucial safety requirement. This calls for specialised tools and methods, such as the usage of pressure-relief tools, safety valves, and materials that are explosion-proof. In order to guarantee the safe

handling and storage of hydrogen fuel, operators and maintenance staff must have the proper training.

The safe operation of FCVs is a further safety measure. This entails including safety measures in the construction of FCVs, such as automatic shutoff valves in the event of a leak or pressure decrease, as well as putting safety procedures in place for fuelling and servicing. Additionally, FCV operators need to obtain adequate instruction in the safe use and upkeep of FCVs.

Safety issues must also be taken into account when building infrastructure for hydrogen fueling. Fueling stations for hydrogen should be built and engineered to meet safety requirements, including having adequate fire suppression and ventilation systems. To reduce the chance of an accident, fueling stations should be placed away from populous areas that have delicate infrastructure.

9.5 LACK OF AWARENESS:

The absence of public and stakeholder knowledge is a significant obstacle to the deployment of hydrogen fuel cell vehicles (FCVs) in India. Many Indians are unaware of the advantages of FCVs, how they operate, and the potential contribution they could make to cutting carbon emissions and enhancing air quality.

The low adoption of FCVs in India compared to other nations is the main cause of the lack of knowledge. There are a number of reasons why the adoption of FCVs, which are still a relatively new technology, has been delayed, including a lack of infrastructure, high pricing, and a dearth of fuel cell vehicles.

A major issue is also the lack of awareness among stakeholders. Stakeholders, such as legislators, automakers, and investors, must actively encourage the use of FCVs. Many of these stakeholders, however, might not completely comprehend the

advantages of FCVs or how they might help lower carbon emissions and enhance air quality. To encourage the use of FCVs through regulations and incentives, policymakers are essential.

By creating and producing more fuel cell cars, automakers can also help to encourage the use of FCVs. However, because of the expensive cost, limited supply, and lack of consumer demand for hydrogen fuel, automakers might not prioritise their creation of FCVs. Additionally, it's possible that automakers do not completely comprehend the advantages of FCVs or are unaware of the potential contribution they could make to cutting carbon emissions and improving air quality.

By funding the advancement of fuel cell technology and infrastructure, investors also play a significant part in encouraging the use of FCVs. However, due to other pressing issues or perceived hazards, investors may not be aware of the potential advantages of FCVs or may not prioritise their investment.

Several actions can be made to encourage increased knowledge among the general public and stakeholders in order to remedy the lack of awareness. First and foremost, there is a need for more outreach and education initiatives to spread the word about the advantages of FCVs and to increase awareness of their potential to lower carbon emissions and enhance air quality.

There are many ways to accomplish this, including advocacy to lawmakers, automakers, and investors as well as public education campaigns, workshops, and events. More support for the adoption of FCVs can be produced by raising knowledge of their advantages and the potential role they may play in combating climate change.

The formation of alliances and partnerships among stakeholders, such as automakers, decision-makers, investors, and non-profit organisations, is another action that may be performed to encourage increased awareness. By cooperating, stakeholders can combine their resources and knowledge to advance the use of FCVs and overcome the issues preventing it.

CHAPTER 10

DEVELOPMENT AND IMPROVEMENT OF HYDROGEN FCVs

The arrival of India's first hydrogen fuel cell bus in December 2017 was one of the noteworthy milestones. The bus, which was created by Tata Motors in collaboration with Indian Oil Corporation, was tested in Mumbai. The Ministry of New and Renewable Energy (MNRE) provided funding for the project, which promoted green and efficient public transport.

The opening of a new fuel cell technology centre at the Indian Institute of Technology (IIT) Delhi in association with the Ministry of New and Renewable Energy (MNRE) was another breakthrough. The center's mission was to create domestic fuel cell technology for a range of uses, such as transportation, fixed power generation, and portable power equipment.

The Indian government also launched steps to encourage the use of hydrogen fuel cell automobiles. The Ministry of Road Transport and Highways released a draft declaration in November 2017 proposing to exempt FCVs from the requirement that corporate transport vehicles have a licence. While the adoption of hydrogen fuel cell vehicles in India was still in its early stages in 2018, a few significant steps and initiatives were taken by the government and industry players to advertise the technology and encourage its adoption in the nation.

At the India-Korea Business Symposium in February 2019, the Hyundai Nexo, the country's first hydrogen fuel cell vehicle, was unveiled. The Nexo wasn't offered for sale in the Indian market; it was displayed as a technology demonstrator. However, this was a big step forward for the nation's hydrogen fuel cell technology.

In 2019, a hydrogen fuel cell bus produced by Indian Oil Corporation (IOC) and Tata Motors was introduced for testing in Delhi. The bus had a 300 km endurance and could be refuelled in about 15 minutes.

Additionally, the Indian government kept up its initiatives to encourage the use of hydrogen fuel cell technology. The Ministry of New and Renewable Energy (MNRE)

unveiled a programme in September 2019 to encourage the study and advancement of fuel cell technology. The programme was intended to speed up domestic fuel cell technology development and encourage its use across a range of industries.

In order to permit the sale and registration of hydrogen fuel cell vehicles in the nation, the Indian government also put up a draft declaration to change the Central Motor Vehicles Rules in 2019. The suggested modification seeks to support the growth of the hydrogen fuel cell car market in India and create a regulatory framework for the commercial application of hydrogen fuel cell technology.

The introduction of the Ather 450X, India's first two-wheeler powered by a hydrogen fuel cell, by Ather Energy was one of the key developments. The Indian Institute of Science (IISc) collaborated in the design and development of the vehicle, which had an 85 km range on a single charge.

The unveiling of the H2Blu initiative by Indian Oil Corporation (IOC) and Israeli business Phinergy was a further development. The goal of the project was to create and test a hydrogen fuel cell system for electric vehicles that might potentially lower fuel cell costs and increase fuel cell efficiency.

Additionally, the Indian government kept up its initiatives to encourage the use of hydrogen fuel cell technology. The National Hydrogen Energy Mission, which sought to develop a hydrogen ecosystem in the nation and encourage the application of hydrogen fuel cell technology in a number of sectors, was unveiled by the Ministry of New and Renewable Energy (MNRE) in June 2020.

The Indian government also put up a drafting policy to encourage the use of hydrogen fuel cell technology there. The plan called for creating a National Hydrogen Energy Board to direct the nation's advancement and marketing of hydrogen fuel cell technology.

In India, the hydrogen fuel cell vehicle (FCV) market continues to grow and expand in 2021, with a focus on raising consciousness, encouraging research and development, and establishing a legal framework for the implementation of hydrogen fuel cell technology.

One of the noteworthy events was the introduction of the Tata Motors' Tata Ace EV, India's first commercial car powered by a hydrogen fuel cell, in January 2021. The vehicle was created in partnership with Indian Oil Corporation (IOC) and was intended to provide businesses with a green last-mile delivery option.

The Indian government also launched a number of measures to encourage the use of hydrogen fuel cell technology. The Ministry of New and Renewable Energy (MNRE) declared the beginning of a pilot project to create a green hydrogen ecosystem in Ladakh in the month of February 2021. The project's goal was to show that it is possible to create green hydrogen utilising renewable energy sources like solar and wind power.

In February 2021, the Indian government initiated the National Hydrogen Energy Mission (NHEM). The mission's objectives are to encourage the use of green hydrogen in various industries and to produce a plan for the country's advancement and adoption of hydrogen fuel cell technology.

Additionally, the Indian government put up a drafting strategy to promote the use of hydrogen fuel cell cars in the nation. The plan included a number of initiatives, including tax breaks, financial aid, and the creation of a legal framework to encourage the use of hydrogen fuel cells.

It is difficult to forecast particular advancements in the infrastructure of India and hydrogen fuel cell vehicle technologies for the years 2022 and 2023. However, it is expected that there will be greater investment and initiatives to encourage the use of FCVs in the nation with the start of the national hydrogen mission and the IOC's intention to build up a pilot hydrogen dispensing station.

CHAPTER

11 CONCLUSION

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India's energy strategy will determine how quickly hydrogen fuel cell vehicles are developed in that nation. India has set challenging goals to

lower carbon emissions and boost the proportion of renewable energy in the nation's

overall energymix. However, hydrogen is not currently given priority in the nation's energy strategy as a fuel. As a result, there isn't enough infrastructure in place to produce, store, and distribute hydrogen fuel. In India, the development of hydrogen fuel cell vehicles is probably going to be delayed without major government funding. The adoption of hydrogen fuel cell vehicles in the nation could therefore be sped up by a comprehensive energy policy that promotes hydrogen as a clean energy source and offers incentives for investing in hydrogen infrastructure.

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